



## On the impact of the assimilation of nacelle winds and yaw angles with WRF-FDDA and WRF-DART for short-term wind energy predictions

**Draxl, Caroline; delle Monache, Luca; Liu, Yubao; Cheng, William; Descombes, Gael; Vandenberghe, Francois; Romine, Glen; Knierel, Jason; Hahmann, Andrea N.; Giebel, Gregor**

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# Assimilation of nacelle winds and yaw angles for Short-Term Wind Energy Predictions

**Caroline Draxl**

Luca delle Monache, Yubao Liu, William Cheng, Gael Descombes, François Vandenberghe, Glen Romine, Jason Knievel (NCAR)  
Andrea N. Hahmann, Gregor Giebel (Risø DTU)

# Forecast errors are expensive



- Trading of wind power on energy markets
- Fluctuating wind and power is challenging for grid operators
- Optimisation of power plant mix
- Maintenance planning
- Enhanced value and acceptance of wind power

Wind turbine measurements become increasingly available and constitute a new set of measurements in the PBL



How to treat them in data assimilation?  
What is their benefit in the system?

# Nacelle winds and yaw angles

Nacelle winds and yaw angles are used by the turbine control system for optimal turbine operation.

## **Nacelle winds:**

Sonic anemometers measure wind on Horns Rev turbines @ 70 m.

**Yaw Angles** for wind directions (u and v in data assimilation):

The nacelle turns itself into the wind.

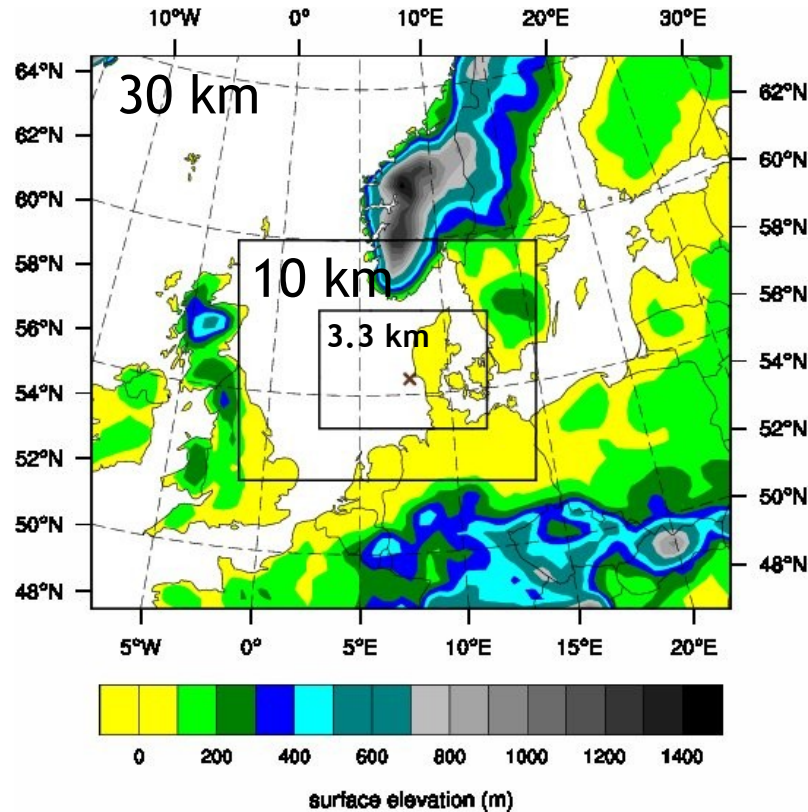


# Issues with nacelle winds

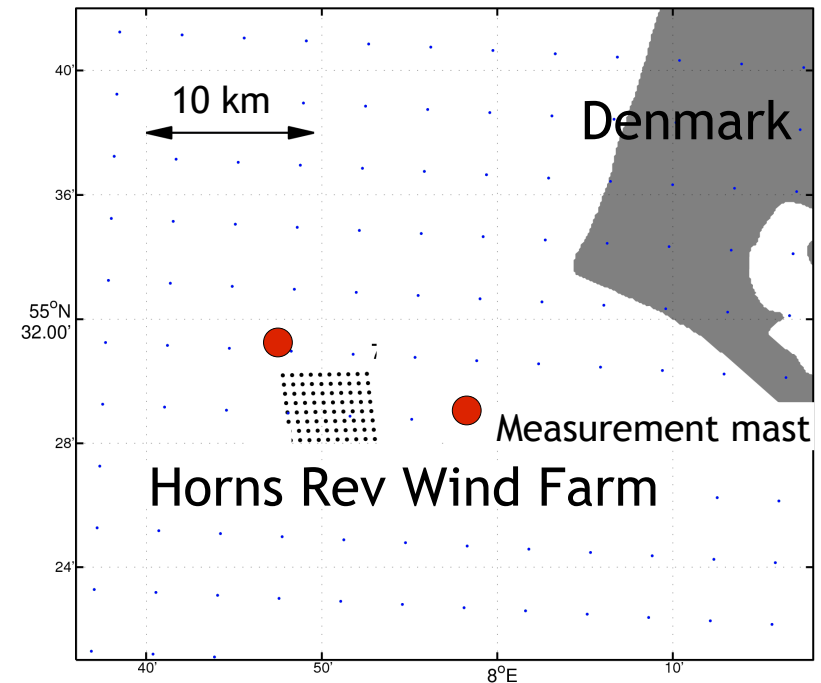
- Disturbance depends on
  - Design of turbine and nacelle
  - Pitch/stall regulation
  - Height of anemometer and position on nacelle
  - Operation/standstill
  - Position in wind farm: wake
- Nacelle transfer function
- Restricted data access



# Wind Farm layout and model setup



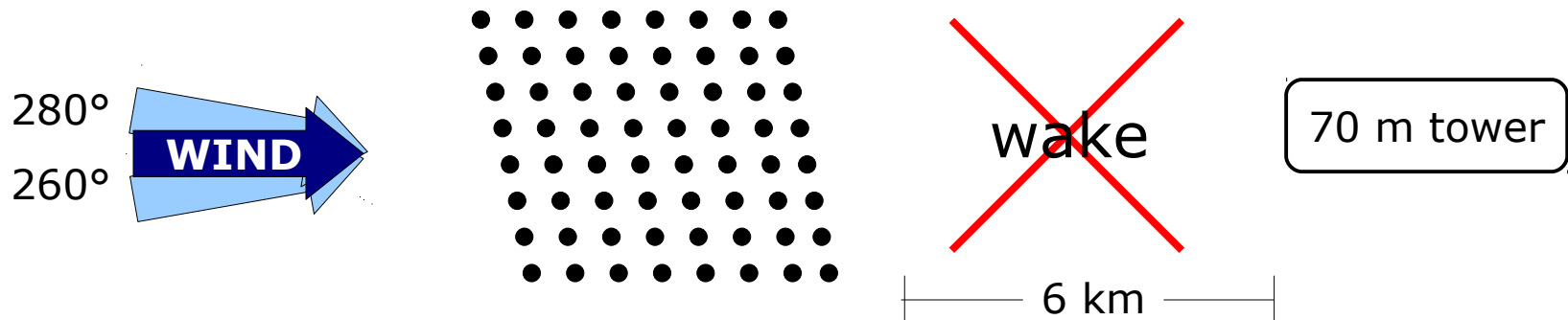
WRF FDDA V3.2.1



Assumption of spatially independent  
obs errors in data assimilation violated

=> data thinning

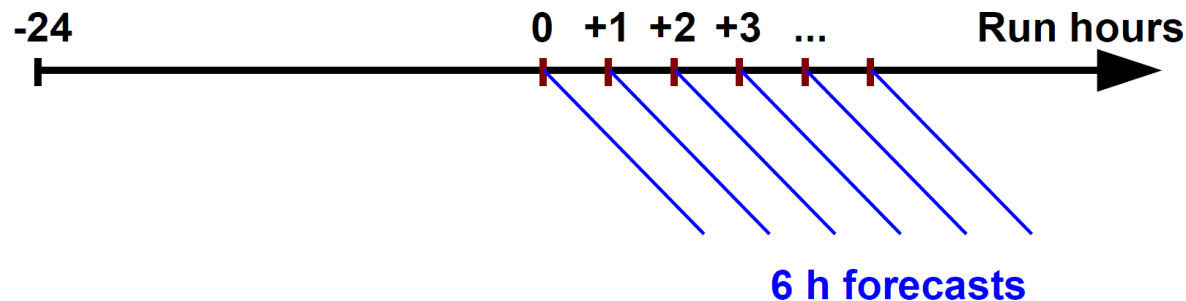
# Find optimal case studies



→ 4 days in 4 different months in 2005:

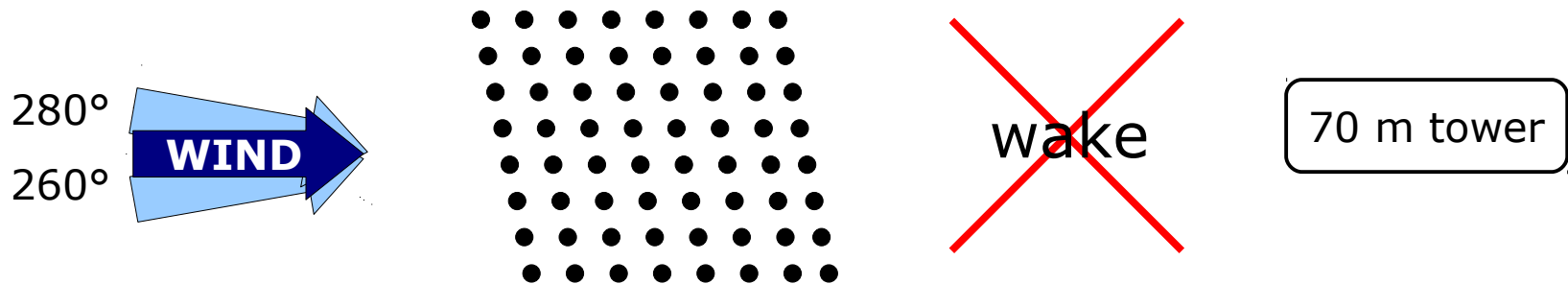
54 hours with a 6h-forecast every hour → 54 forecasts

low pressure over northern Europe, pre or post cold front





# Data thinning

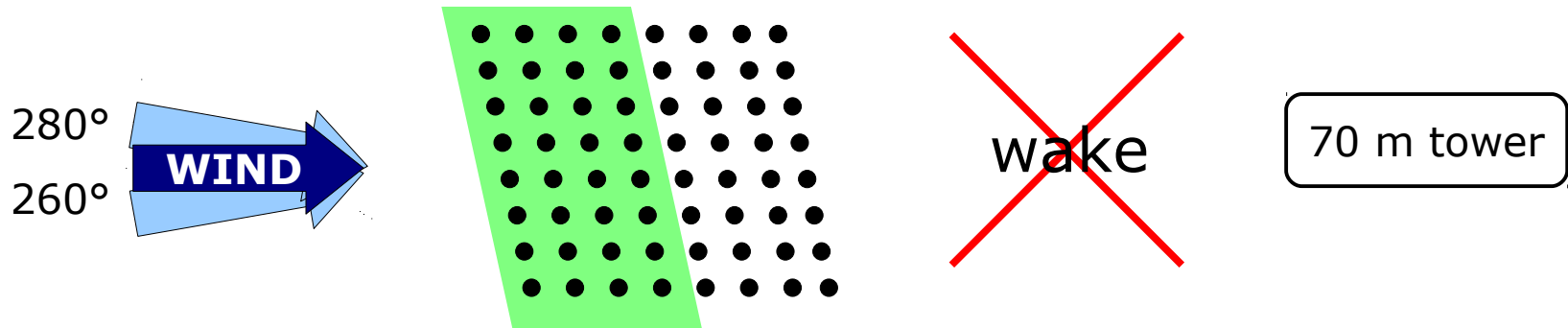


Statistics compared for different turbine groups

Medians of  
all turbines

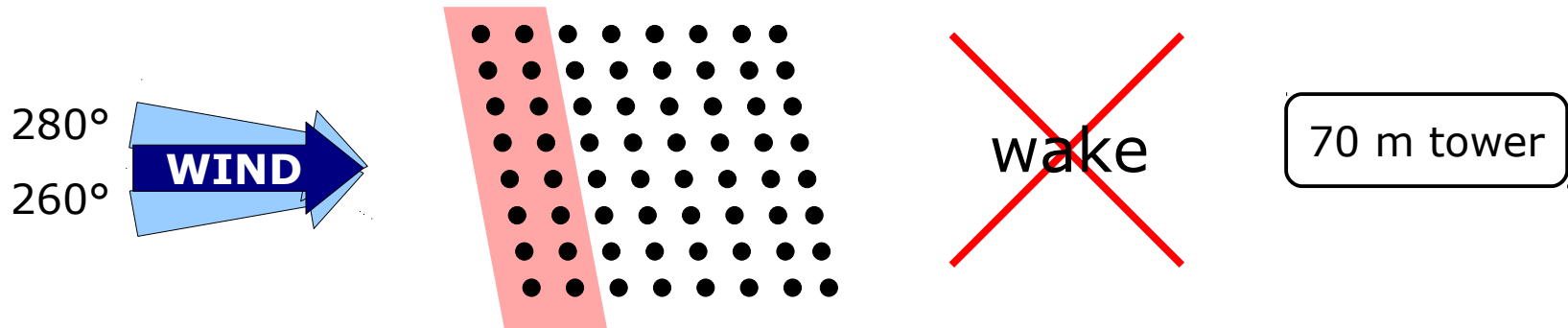


# Data thinning



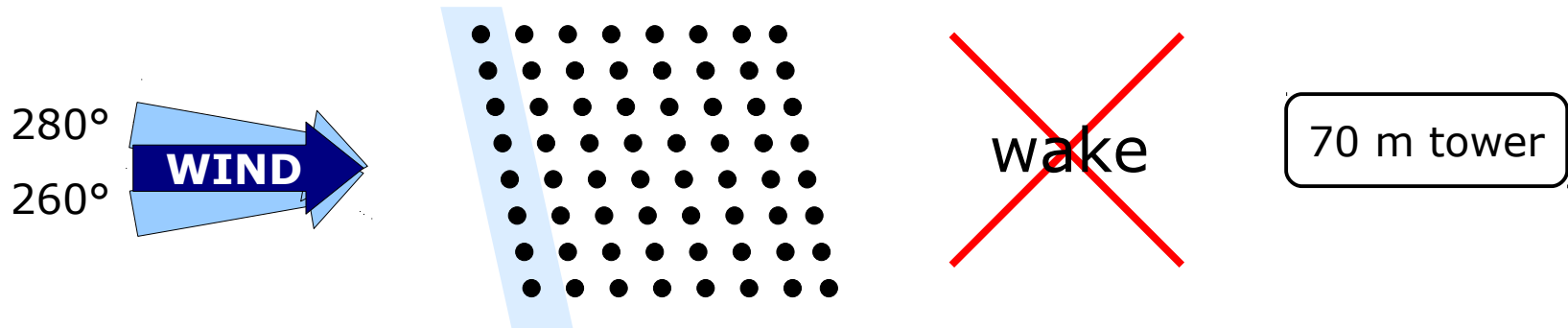
Medians of  
all turbines  
upwind half farm

# Data thinning



Medians of  
all turbines  
upwind half  
first 2 upwind turbine rows

# Data thinning

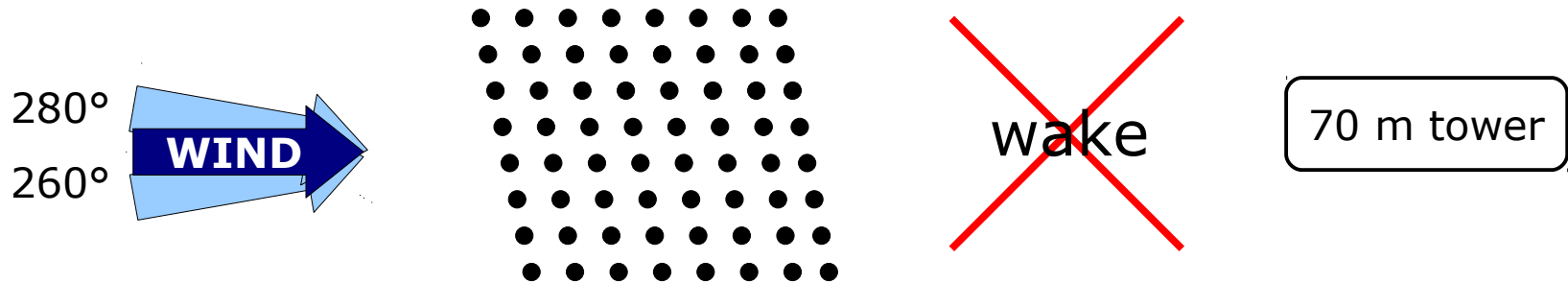


Medians of

- all turbines
- upwind half
- first 2 upwind turbine rows
- first upwind turbine row

Direction measurements from turbine yaws

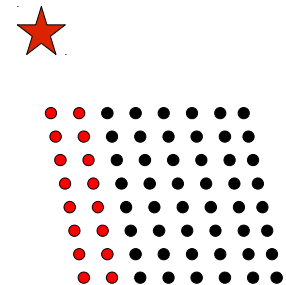
# Data thinning



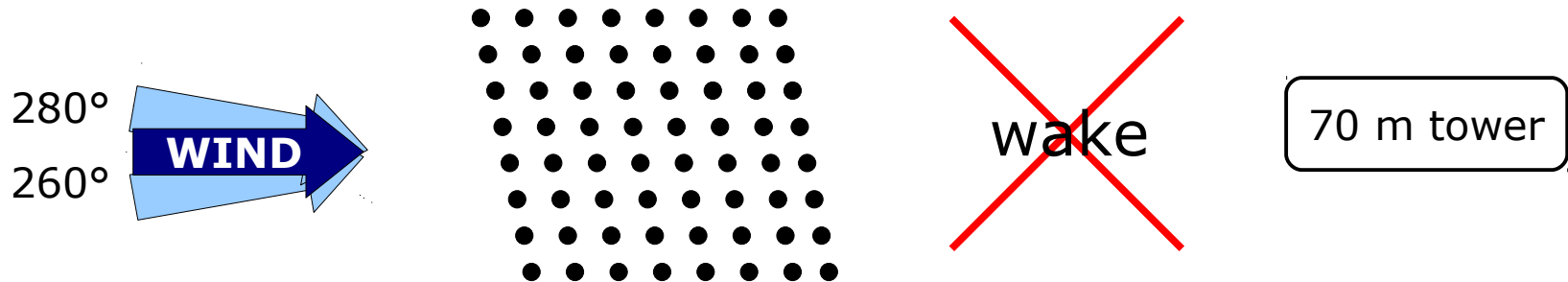
Medians of

- all turbines
- upwind half
- first 2 upwind turbine rows
- first upwind turbine row

Direction measurements from turbine yaws  
and from 68 m tower to the north of the farm



# Data thinning



Medians of

all turbines

upwind half

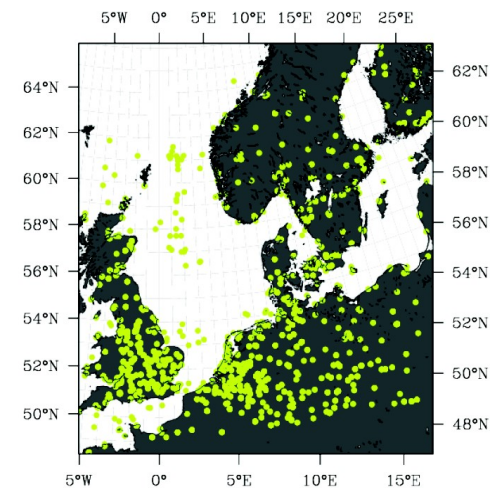
first 2 upwind turbine rows

first upwind turbine row

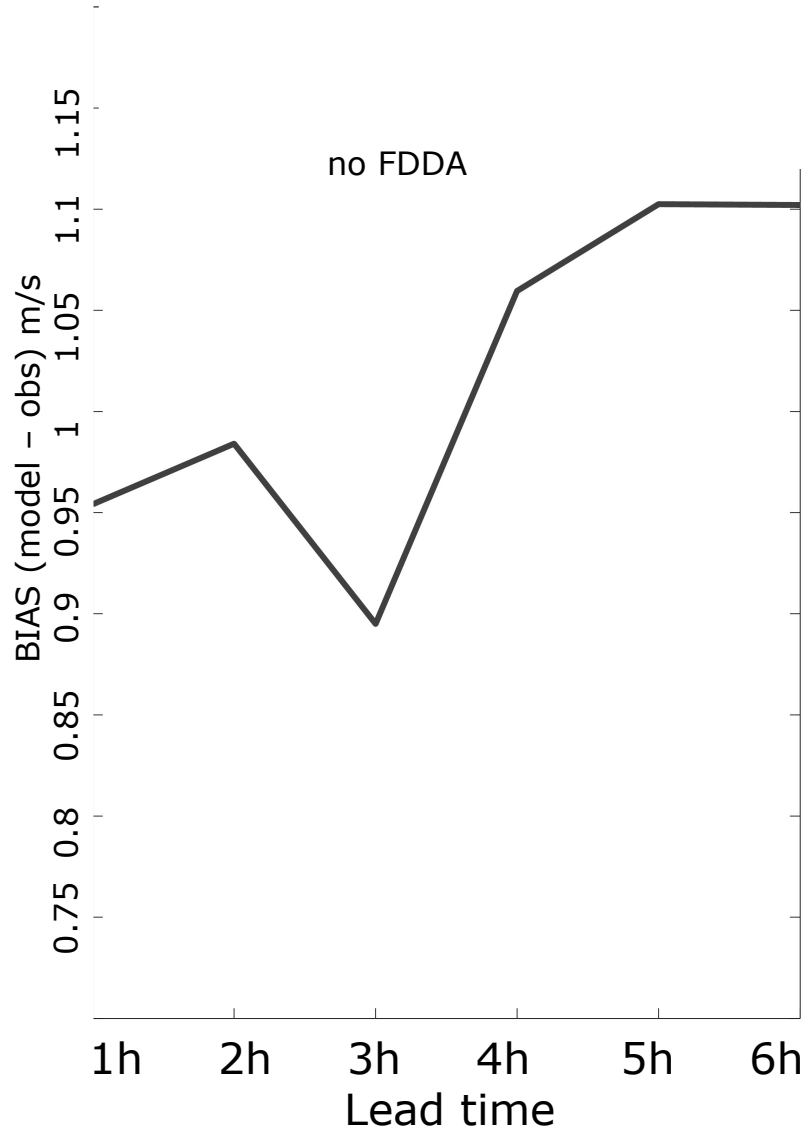
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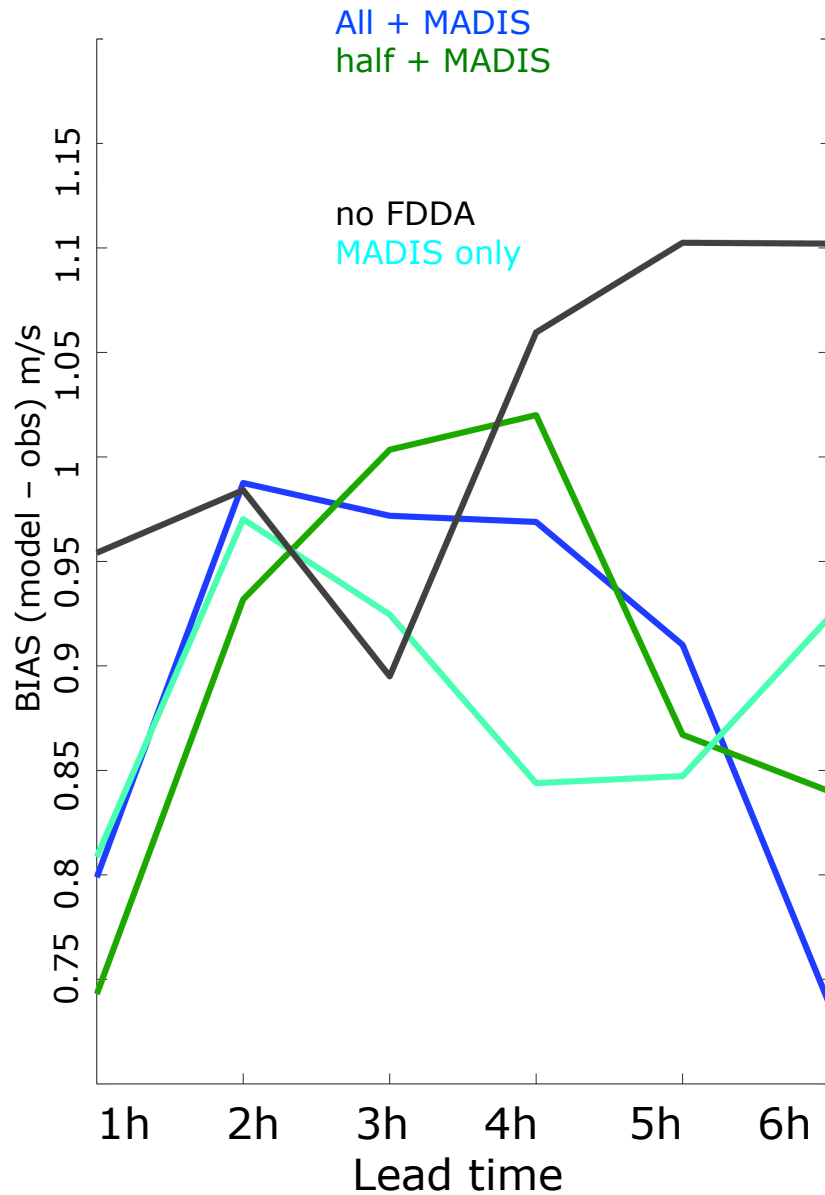
+ METAR, SYNOP, ACARS, Radiosondes, Ships



# Bias reduced in first 2 hours, noisy

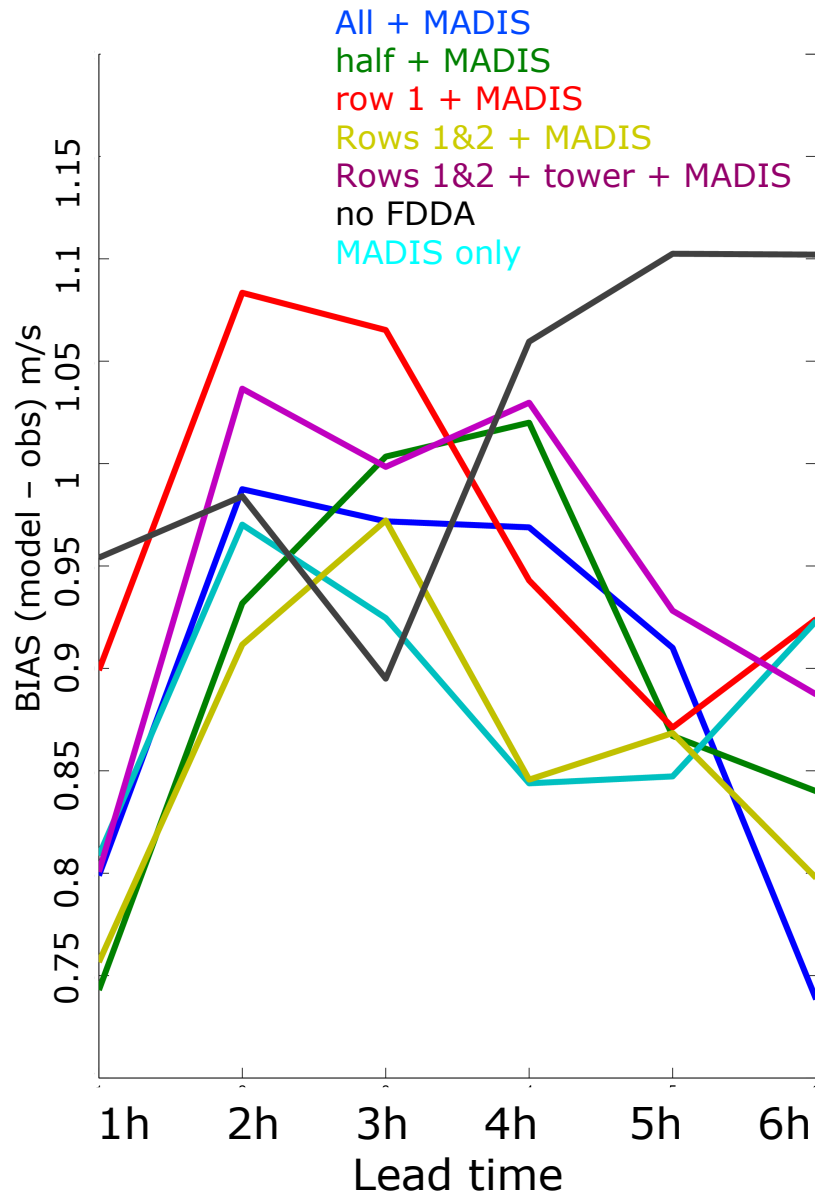


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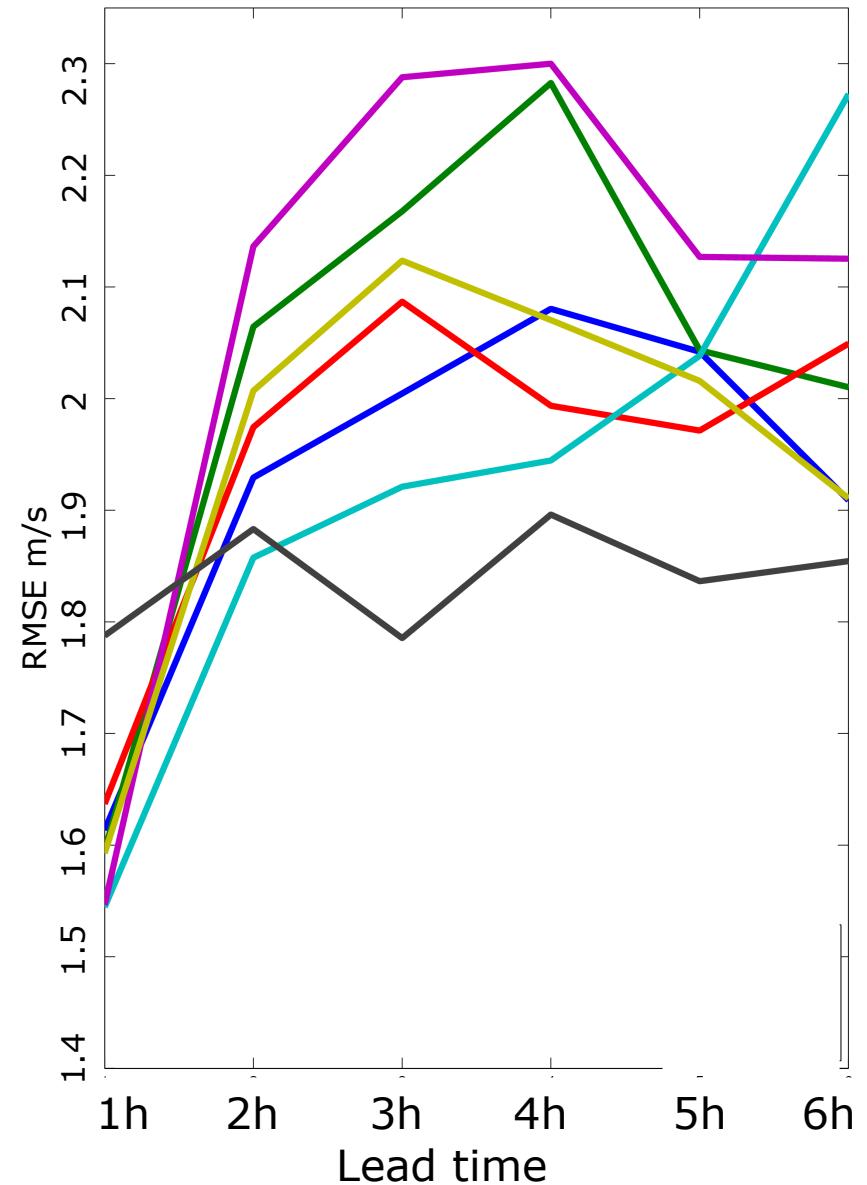
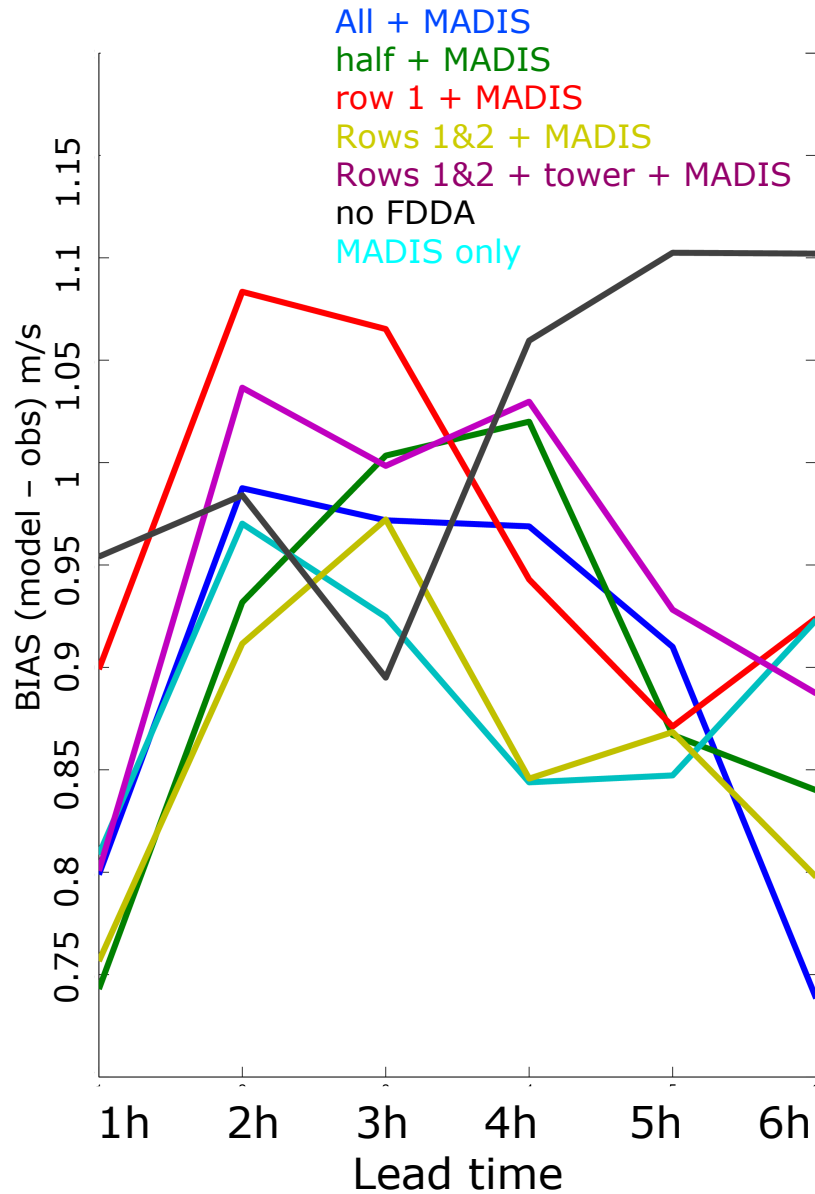




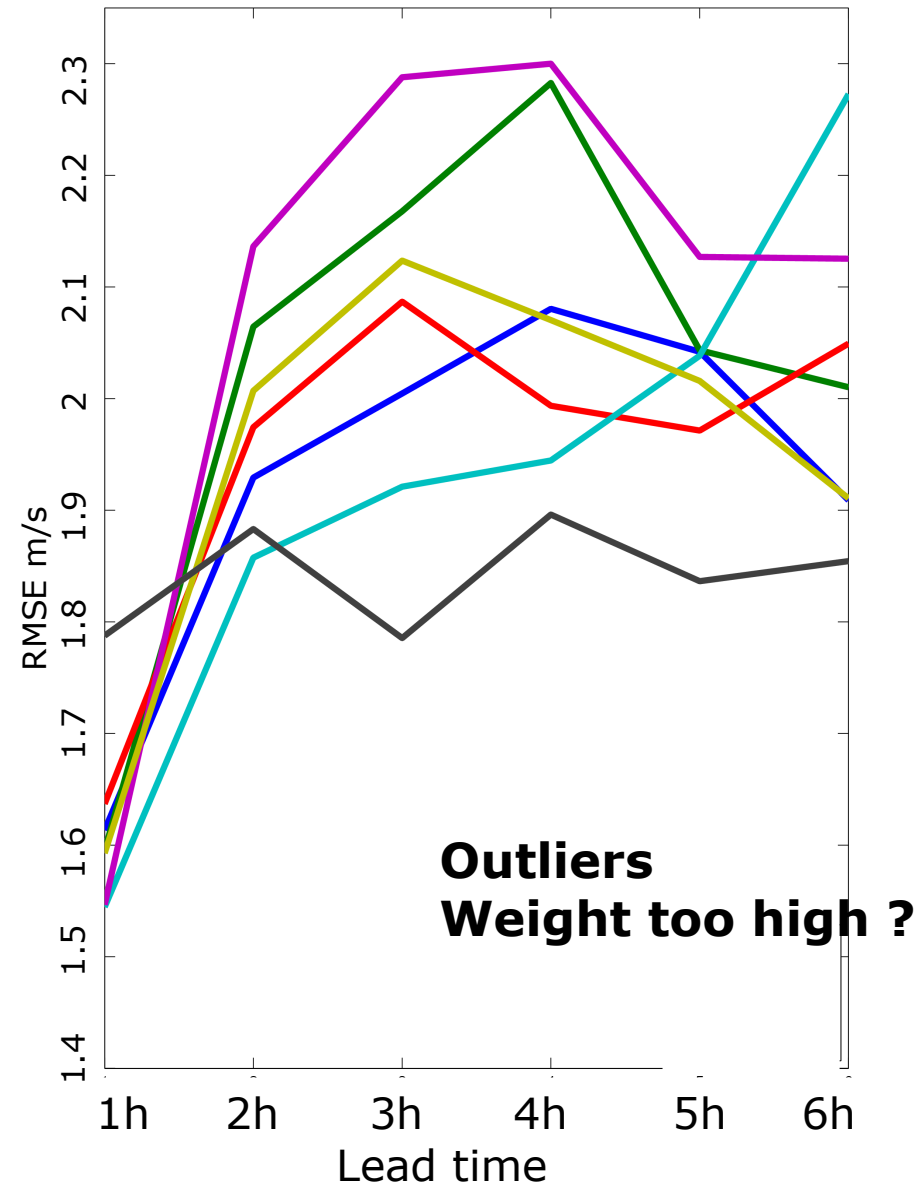
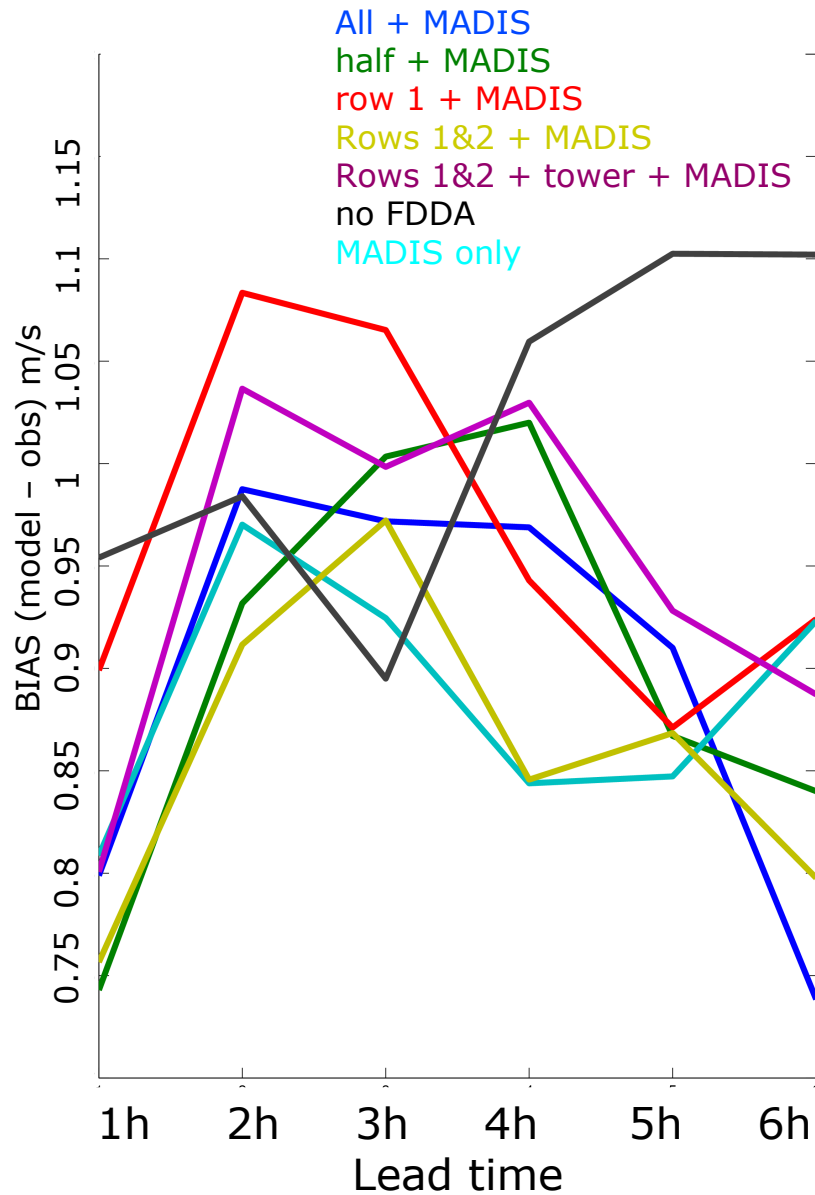
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# Bias reduced in first 2 hours, noisy



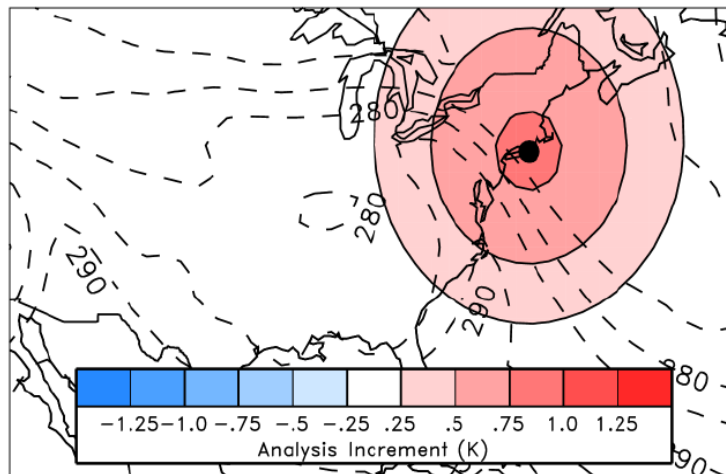
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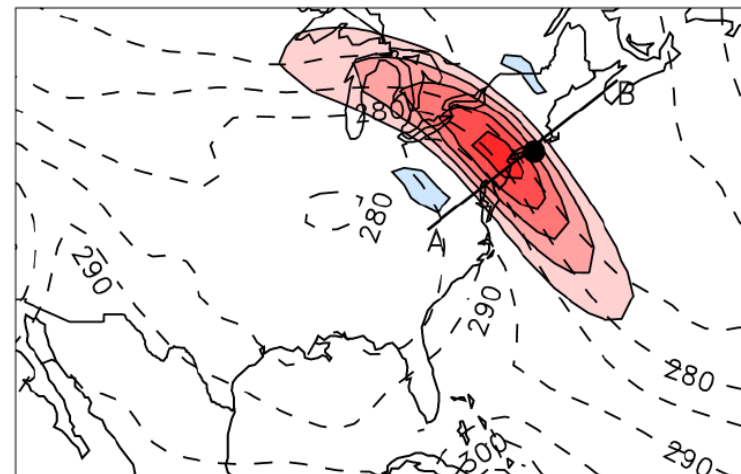
# WRF DART and plans

DART: Community Ensemble Kalman filter system maintained by NCAR

3D-VAR, FDDA increment



EnKF increment



Source: Tom Hamill, <http://www.esrl.noaa.gov/psd/people/tom.hamill>

- EnKF: flow-dependent background error covariances.
- Observation error needs to be assigned to measurements – knowledge of measurements is important.  
Observation errors are used by EnKF as a weight for the information provided by the measurements.

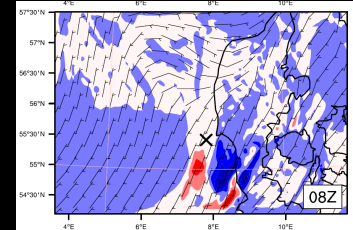
# A new growing & promising data set



**Improve  
forecasts inland**

**CAREFUL  
with nacelle  
winds !!!**

**Thinning  
strategies**



**FDDA:  
2 hour benefit**

**WRF DART  
More promising ?**



**Assimilation  
in the PBL**

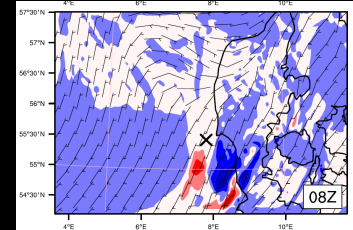
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**Assimilation  
in the PBL**

wind direction 200507191300–200507200800

